UBC Physics 102

Lecture 13

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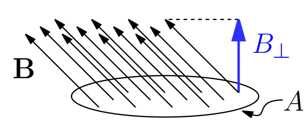
Outline

- ▷ Faraday's law and Lenz's law
- ▷ Emf in a moving conductor
- ▷ Transformers
- ▷ Self-inductance
- ▷ Energy storage
- ▷ End

Faraday's law and Lenz's law [Text: Sect. 29-1,2]

- **Definition:** *Magnetic flux*



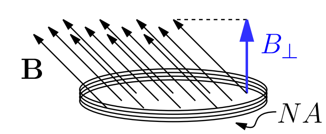
- Quantity of B-field passing through area A.

$$\Phi_B = B_\perp A.$$

- Like Φ_E used in Gauss's law but don't need closed surface.
- Don't get to choose surface, is defined by a loop of wire.

Faraday's law and Lenz's law, contd

- **Definition:** *Magnetic flux, contd*



- If we have a coil with N loops then same B goes through all so

$$\Phi_B = NB_\perp A.$$

Faraday's law and Lenz's law, contd

- **Unit: Weber,** Wb
  - Unit of B-flux,

$$1\ \mathrm{Wb} = 1\ \mathrm{T}\cdot\mathrm{m}^2.$$

- **Discussion: Induced emf**
  - Have seen current produce B-fields.
  - Can B-fields produce currents?
  - Steady B-fields *cannot* but changing B-fields *can*.
- **Definition:** *Induced current/emf*
  - The current or voltage produced by a changing B-field.

Faraday's law and Lenz's law, contd

- **Definition:** *Faraday's law*
  - Changing flux induces emf equal to rate of change,

$$\mathscr{E} = -\frac{d\Phi_B}{dt}.$$

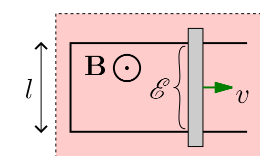
  - Third of Maxwell's equations.
  - Minus sign indicates direction of emf, or can use Lenz's law.
- **Definition:** *Lenz's law*
  - Induced emf (and current) in direction that opposes change in flux.

Faraday's law and Lenz's law, contd

- **Discussion: Induced magnetic field**
  - Changing flux induces emf.
  - Emf produces current.
  - Current generates B-field.
  - Generated B-field "tries" to compensate for change in flux.
  - Use RH-field rule to determine direction of current.
- **Interactive Quiz: PRS 13a**

Emf in a moving conductor [Text: Sect. 29-3]

- **Discussion: Moving conductor**
  - Can induce emf by changing B-field or area.
  - Consider circuit: moving rod on conducting rails.



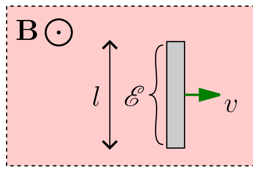
$$\frac{dA}{dt} = lv.$$

  - Emf is (ignoring sign)

$$\mathscr{E} = \frac{d}{dt}\Phi_B = B\frac{dA}{dt} = Blv.$$

Emf in a moving conductor, contd

- **Discussion: Moving conductor, contd**
  - Compare to isolated moving rod.



  - Force on electrons, $\boxed{F = qvB}$ (up). So E-field in rod (down) is

$$E = \frac{F}{q} = vB.$$

Emf in a moving conductor, contd

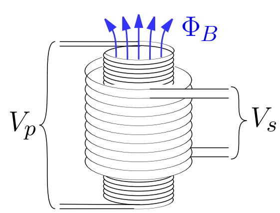
- **Discussion: Moving conductor, contd**
  - $\mathbf{E}$ uniform so emf (voltage, $\boxed{V = -E_l l}$, ignoring sign)

$$\mathscr{E} = El = Blv.$$

  - Same as before!
- **Interactive Quiz: PRS 13b**

Transformers [Text: Sect. 29-6]

- **Derivation: Transformers**
  - Faraday's law works both ways: source emf creates change in B-field flux.
  - Can be used to "couple" 2 isolated circuits:



  - Primary coil with voltage V_p generates flux:

$$V_p = N_p \frac{d\Phi_B}{dt}.$$

Transformers, contd

- **Derivation: Transformers, contd**
  - Flux induces voltage V_s in secondary coil:

$$V_s = N_s \frac{d\Phi_B}{dt}.$$

  - Flux (per loop) same through both so voltages related by

$$\boxed{\frac{V_p}{N_p} = \frac{V_s}{N_s}.}$$

  - If transformer efficient then power transferred from primary to secondary, $P_p = P_s$ or $I_p V_p = I_s V_s$.

Self-inductance [Text: Sect. 30-2]

- **Derivation: Self-inductance**
  - Current in a coil creates flux through own loops.
  - B-field given by $\boxed{B = \mu_0 \frac{N}{l} I}$ so total flux is

$$\Phi_B = NBA = \frac{\mu_0 N^2 A}{l} I.$$

  - Faraday's law says if flux changes then emf induced:

$$\mathscr{E} = -\frac{d\Phi_B}{dt} = -\left(\frac{\mu_0 N^2 A}{l}\right)\frac{dI}{dt}.$$

  - So changing current induces emf.
  - Emf "impedes" change in current.

Self-inductance, contd

- **Definition:** *Self-inductance,* L
  - Magnitude of voltage "response" to changing current,

$$\boxed{\mathscr{E} = -L\frac{dI}{dt}.}$$

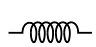
  - Self-inductance is proportionality constant, L.
  - Property of object: depends on shape, size, etc. For solenoid,

$$\boxed{L = \frac{\mu_0 N^2 A}{l}.}$$

Self-inductance, contd

- **Definition:** *Self-inductance, contd*
  - $\mathscr{E} = 0$ if current constant. $\mathscr{E} > 0$ means voltage drop (first end at "higher" potential).
- **Unit: Henry,** H
  - Unit of inductance,

$$\boxed{1\ \mathrm{H} = 1\ \Omega \cdot \mathrm{s}.}$$

- **Definition:** *Inductor*
  - A circuit component with self-inductance.
  - Circuit symbol: 

Energy storage [Text: Sect. 30-3]

- **Interactive Quiz: PRS 13c**
- **Derivation: Energy storage**
  - Saw (Lecture 8) capacitors store energy $\boxed{U = \frac{1}{2}CV^2}$ in E-field.
  - Similarly, inductors store energy in B-field.
  - Consider gradually ramping up current $\hat{I}$ through inductor from zero to I.
  - Emf induced $\mathscr{E} = -L\frac{d\hat{I}}{dt}$. Power used by inductor,

$$P = \left|\hat{I}\mathscr{E}\right| = L\hat{I}\frac{d\hat{I}}{dt}.$$

Energy storage, contd

- **Derivation: Energy storage, contd**
  - Power not lost to heat, but stored as potential energy,

$$\begin{aligned} U &= \int P\,dt = \int L\widehat{I}\frac{d\widehat{I}}{dt}dt \\ &= L\int_0^I \widehat{I}\,d\widehat{I} \end{aligned}$$

$$U = \frac{1}{2}LI^2.$$

End

- **Practice Problems:**
  - Ch. 29: Q. 1, 3, 5, 7, 9, 11, 19.
  - Ch. 29: Pr. 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 37, 39, 41, 43, 45, 55, 57, 59, 63, 65.
- **Midterm Test: #3**
  - Third 60 min. test at start of class on Mon (Jul 21).
  - Will cover all material in Lectures 9–13 (except Ch. 30) and Ch. 25 from Lecture 8.
- **Interactive Quiz: Feedback**
- **Tutorial Question: tut13**